

Flavor tagging tools: flavor tagging at e+e− facilities

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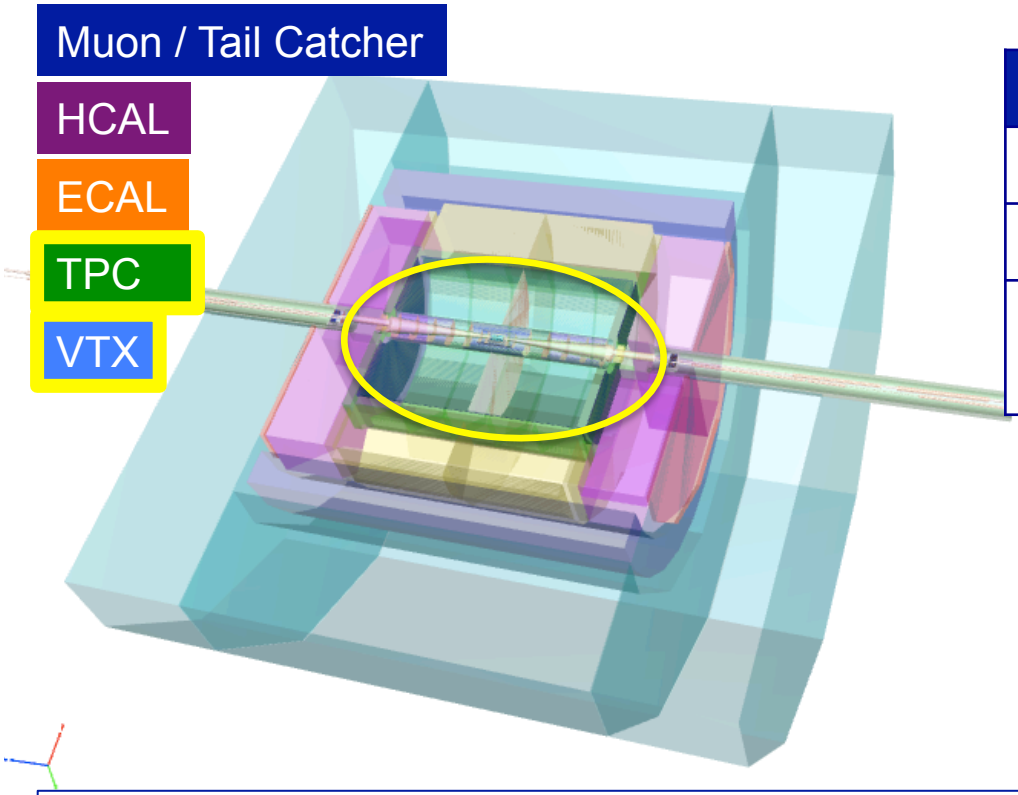
Introduction

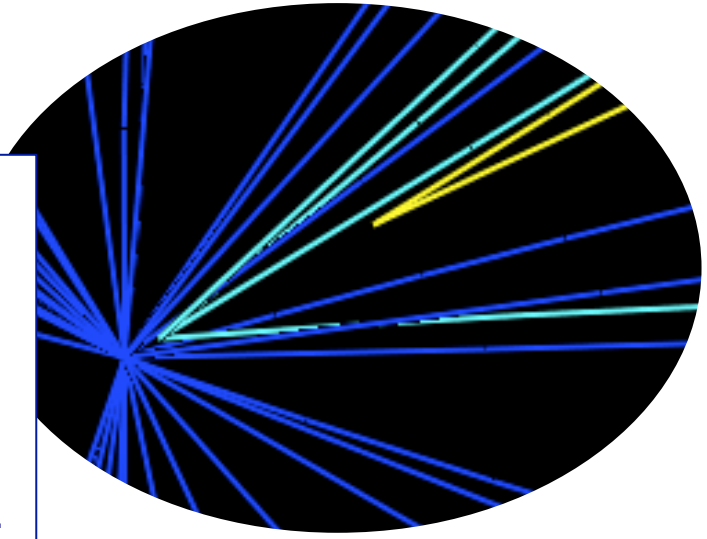
- Flavor tagging is crucial in **e+e− physics**
  - e.g. **h→bb/cc, t→bW, H^0A^0→bbbb**
- Key ideas: vertex finding over the whole event
  - Secondary & tertiary vertex reconstruction made possible by low background environment & excellent position resolution of the detectors
- Challenges:
  - environment with **many jets**
    - e.g. e+e−→tth→bqqbqqbb **(8 jets)**
- Tools developed for physics studies at **ILC / CLIC**:
  - LCFIVertex [NIM A 610 573 (2009)]
  - LCFI+ [https://confluence.slac.stanford.edu/display/ilc/LCFIPlus]
  - developed for the latest physics studies for the ILC TDR using **full detector simulation**

Detector Requirements



Vertex Detector (ILD / SiD)	
Inner radius	15 / 14 mm
Outer radius	60 mm
Impact parameter resolution	< 5 μm (high mom.)

Tracker: Track selection / V^0 rejection
Calorimeters: Lepton ID / PFA



Track impact parameter resolution goal at ILC:

$$\sigma_{r\phi} = 5\ \mu\mathrm{m} \oplus \frac{10}{p(\mathrm{GeV})\sin^{3/2}\theta}\ \mu\mathrm{m}.$$

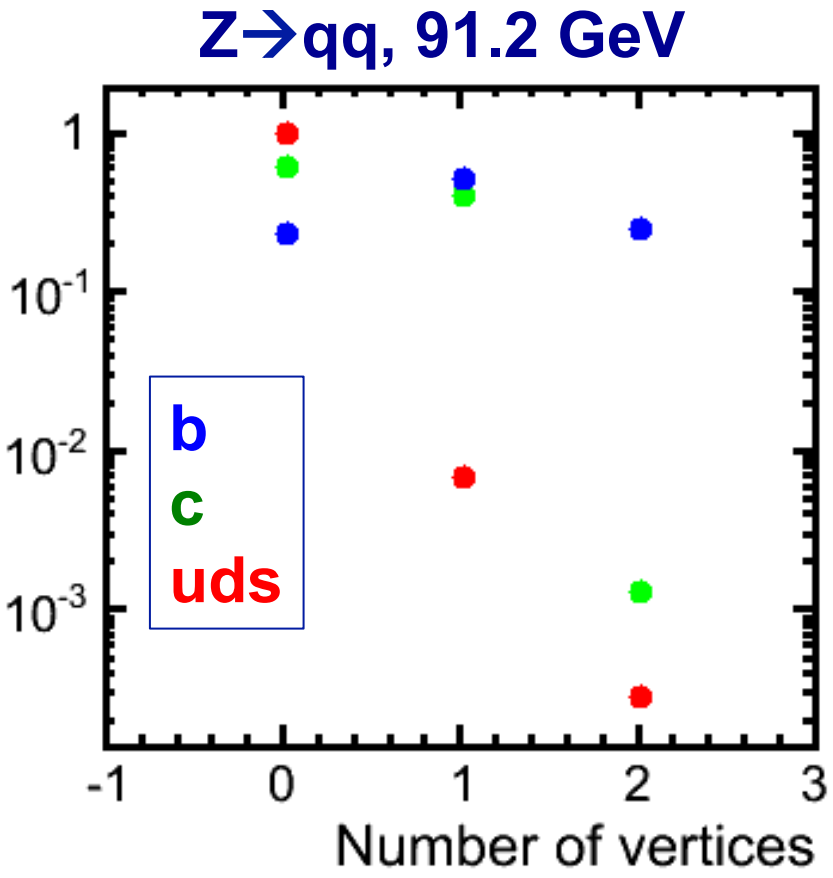
Ensures good track measurement and flavor tagging.

Input variables

Input variables use information from

- **jets:** tracks, neutrals
- **tracks:** impact parameters & covariance, lepton ID
- **vertex:** position, direction, momentum, mass

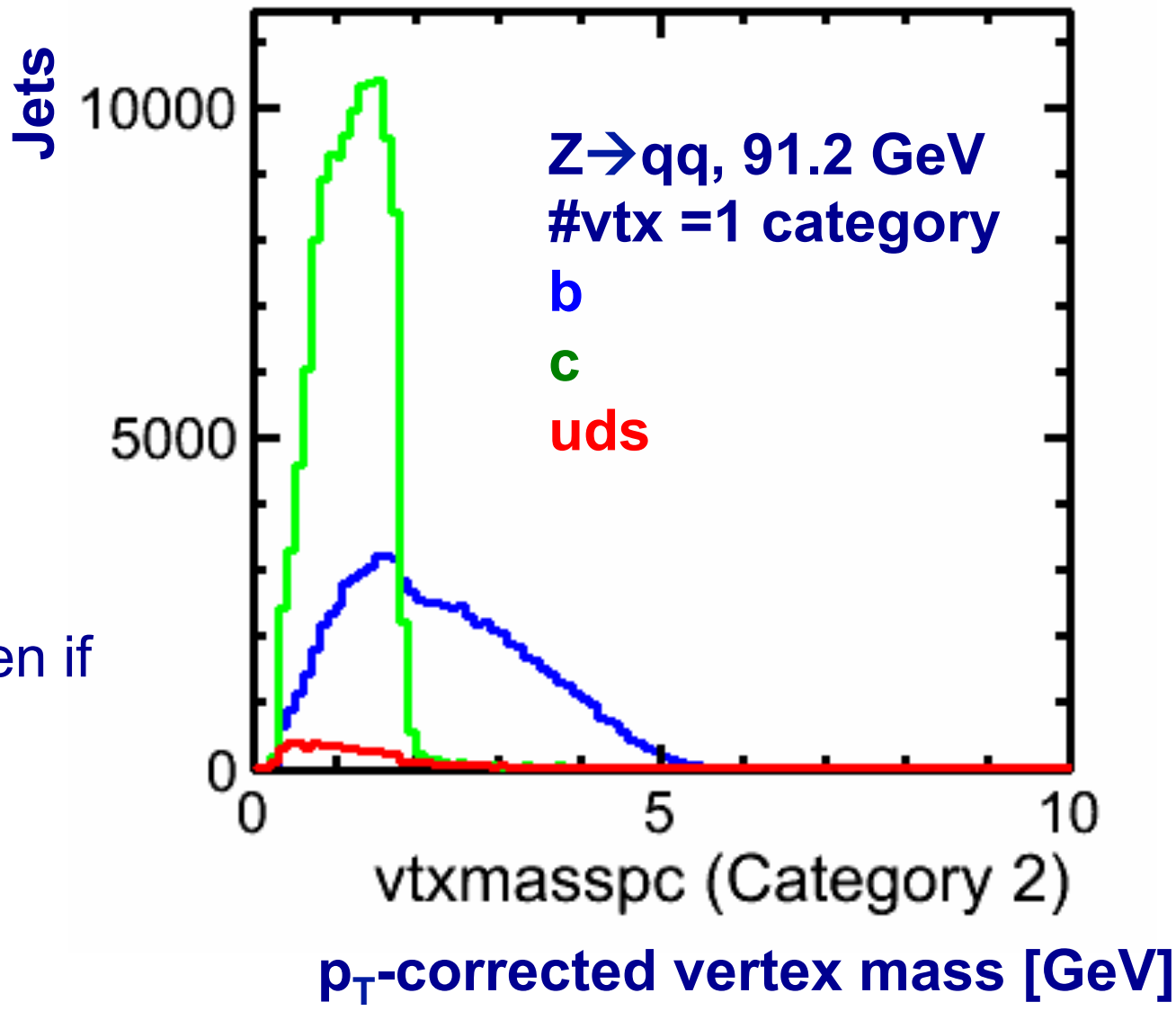
TMVA multiclass BDT with gradient boost in 3 classes (b, c, uds) and 4 categories



Vertex finder performance

Zhh → qqbbbb	Primary	b hadron	c hadron	other
# all reco. tracks	67575	12912	15246	4087
# tracks in vertex	617	8717	10529	358

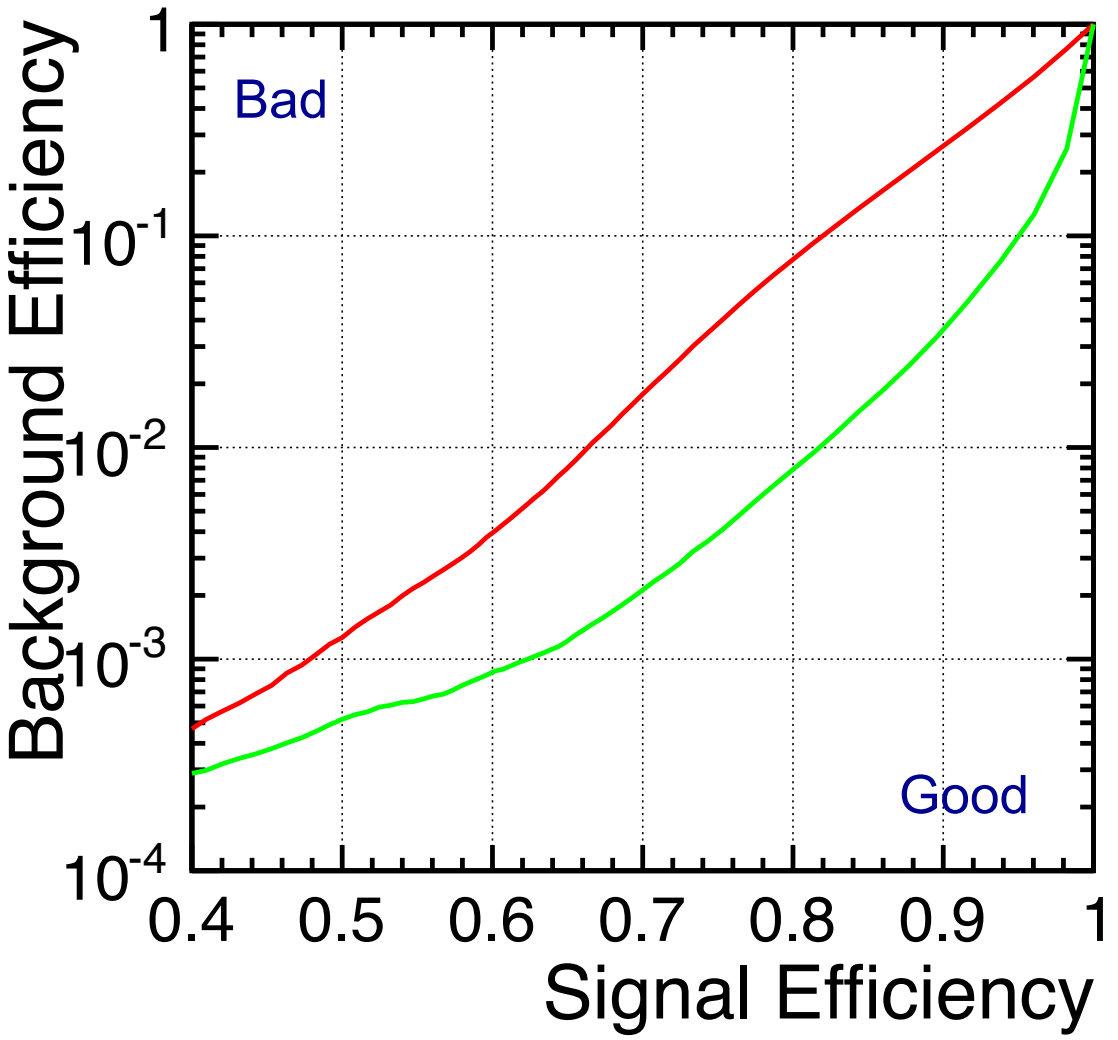
Example



Strong b/c separation even if the number of reconstructed vertex is 1

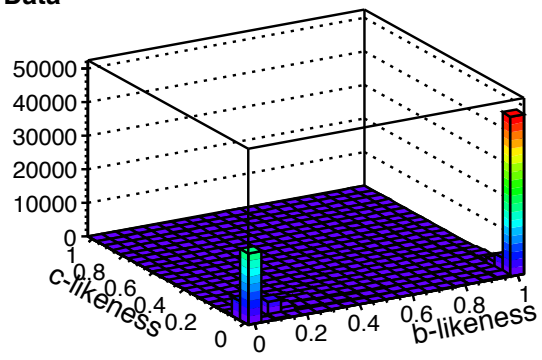
Performance

Z→qq, 91.2 GeV
c background
uds background

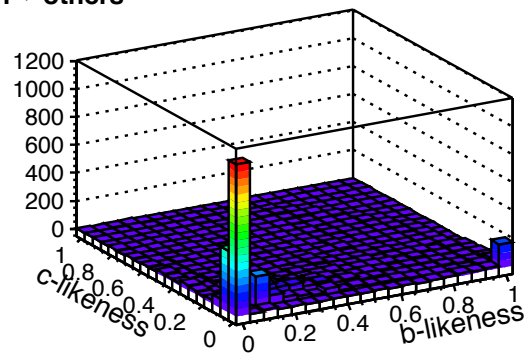


Performance: vvH at 1 TeV

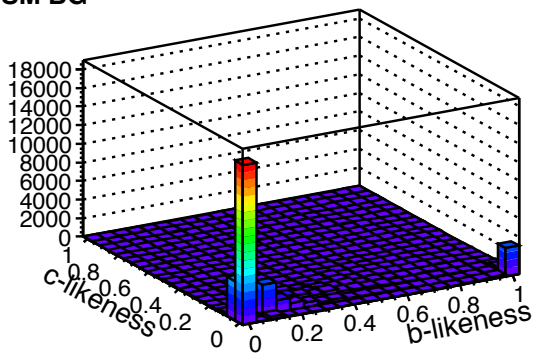
Data



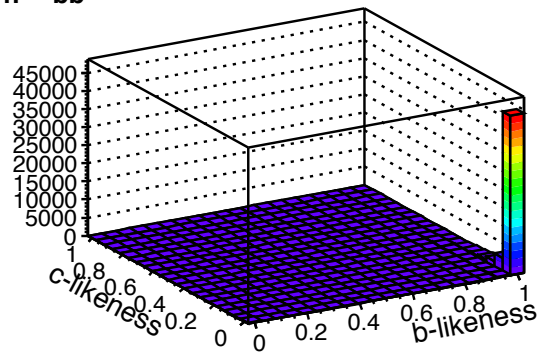
h→ others



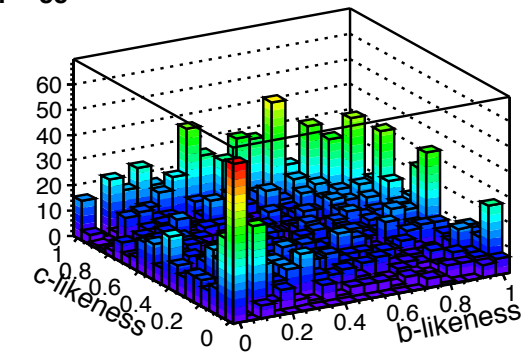
SM BG



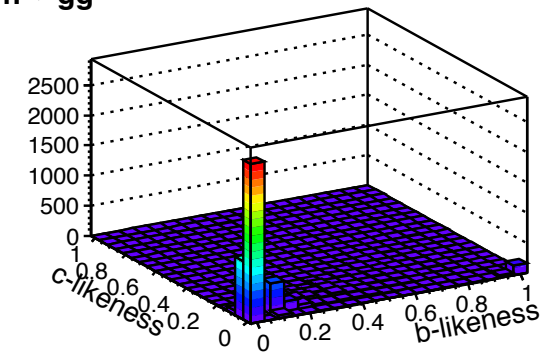
h→ bb



h→ cc



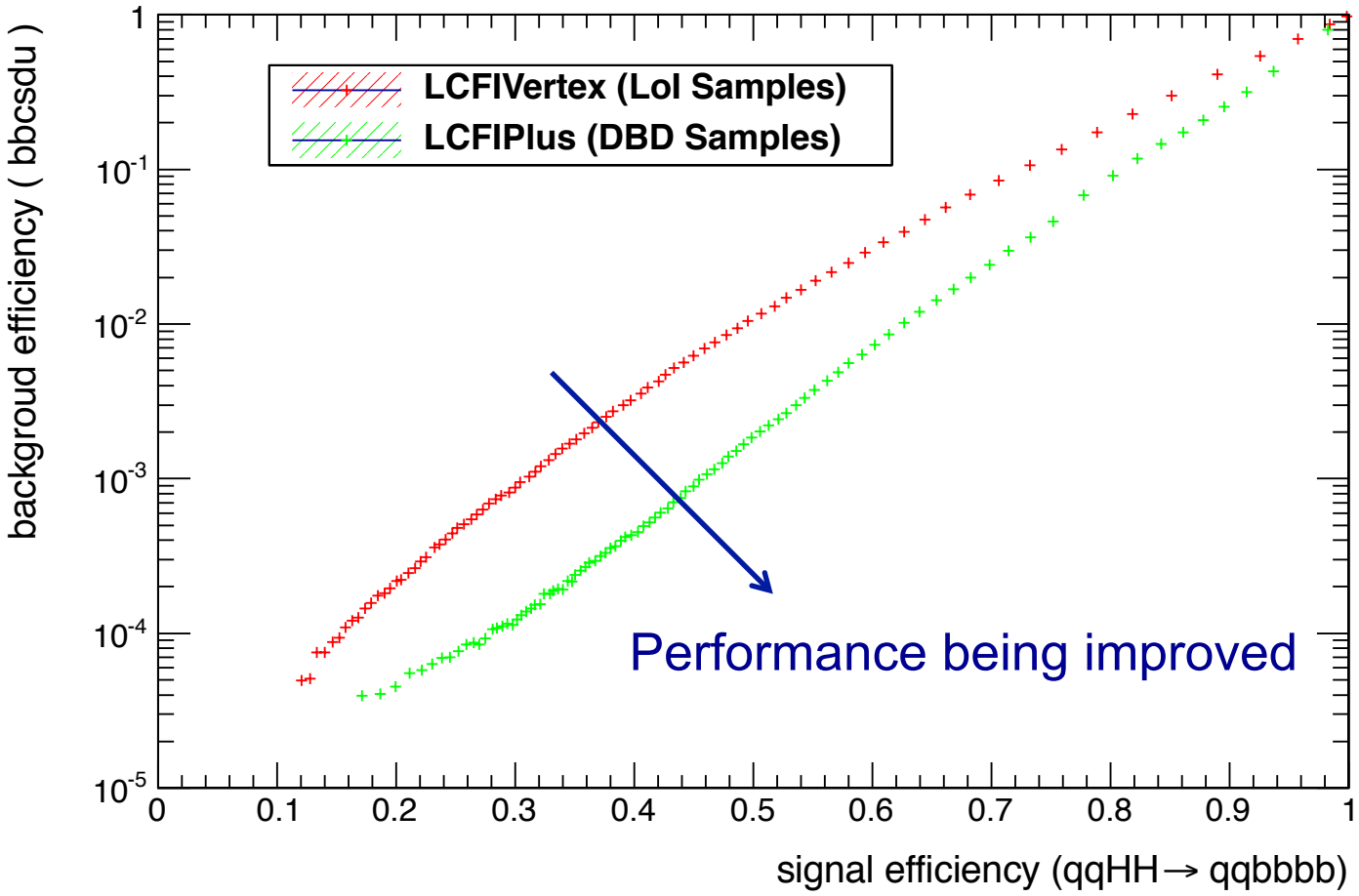
h→ gg



Hiroaki Ono, vvH at 1 TeV, H→bb,cc,gg (ILD)
Distributions used for template fits.

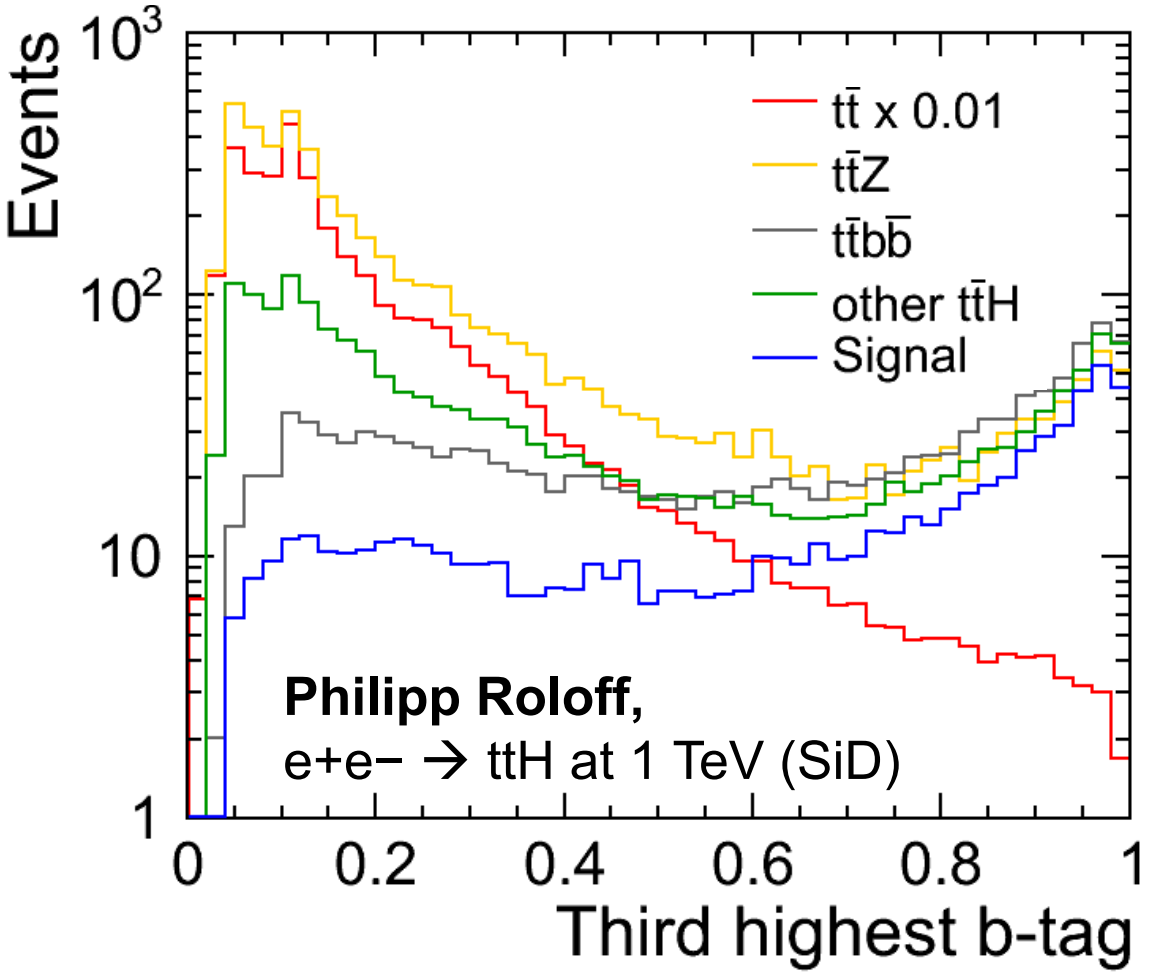
c-tagging capabilities are also demonstrated.

Performance: ZHH at 500 GeV



Junping Tian, e+e− → ZHH at 500 GeV (ILD)

Performance: ttH at 1 TeV



Performance demonstrated for:
1) Different detector geometry, and 2) Higher jet energies

Summary

- Flavor tagging crucial for **e+e- physics** studies
- Current algorithm rather simplistic approach: input variables based on tracks, vertices → multivariate analysis
- Performance **demonstrated** with full simulation studies under realistic conditions for various jet energies
- **But still a lot to do:**
  - Improve vertex finding, jet finding, lepton ID
  - Systematic uncertainties to be evaluated with control samples e.g. e+e- → ZZ/ZH, e+e- → qq

Extra Slides

Implementation

LCFI+ Data

Tracks, Neutrals, Vertices, Jets, …

- Automatic type identification
  (Allow one name with multiple types)
- Automatic creation/deletion
  (using ROOT class dictionary)

LCIO Data

- Automatic conversion from LCIO to lcfiplus classes
- Conversion to LCIO invoked by processor

configure

Algorithms

Vertex Finder, Jet Finder, Flavor Tagger, …

- Parameters class used for type-safe configuration

LcfiplusProcessor

Marlin processor

- Marlin parameters control algorithms
- LCIO I/O configuration

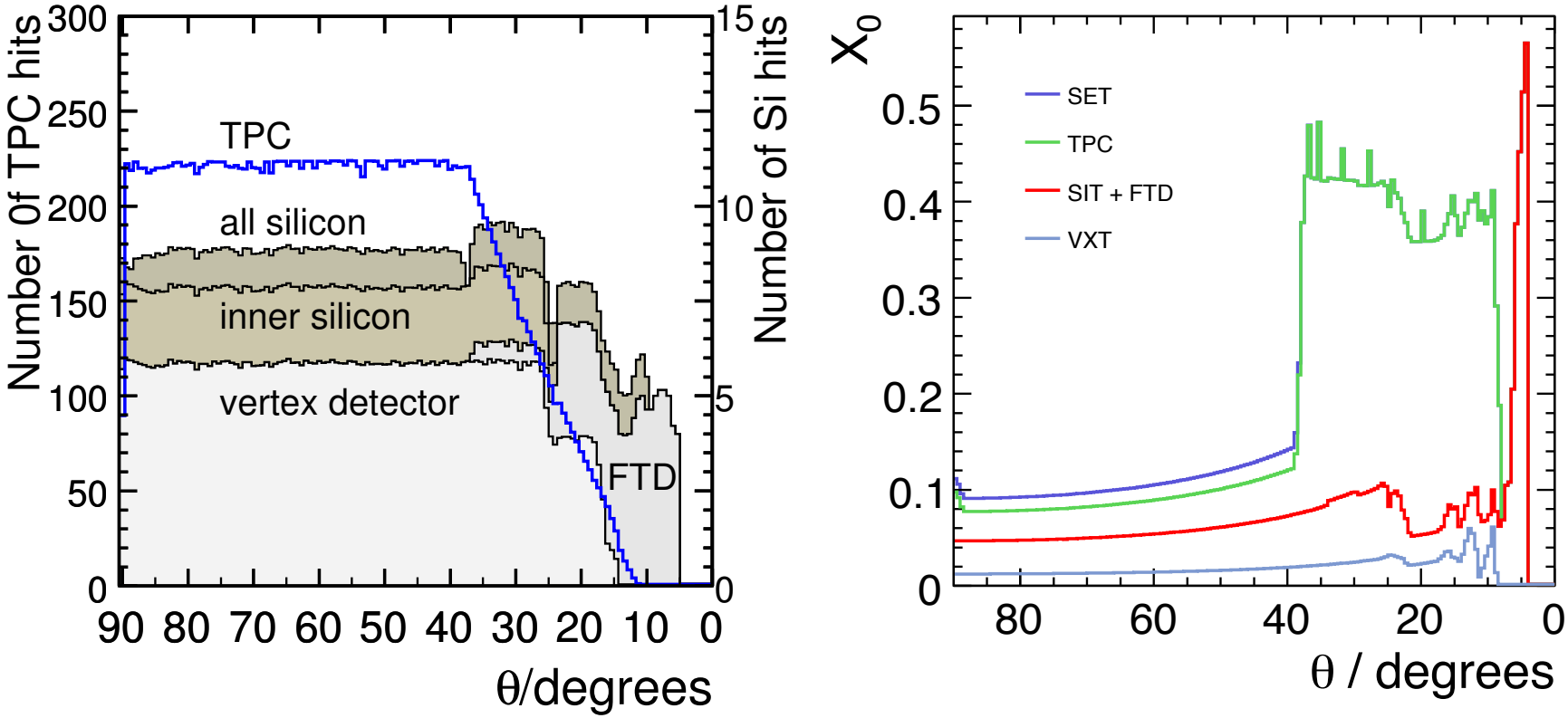
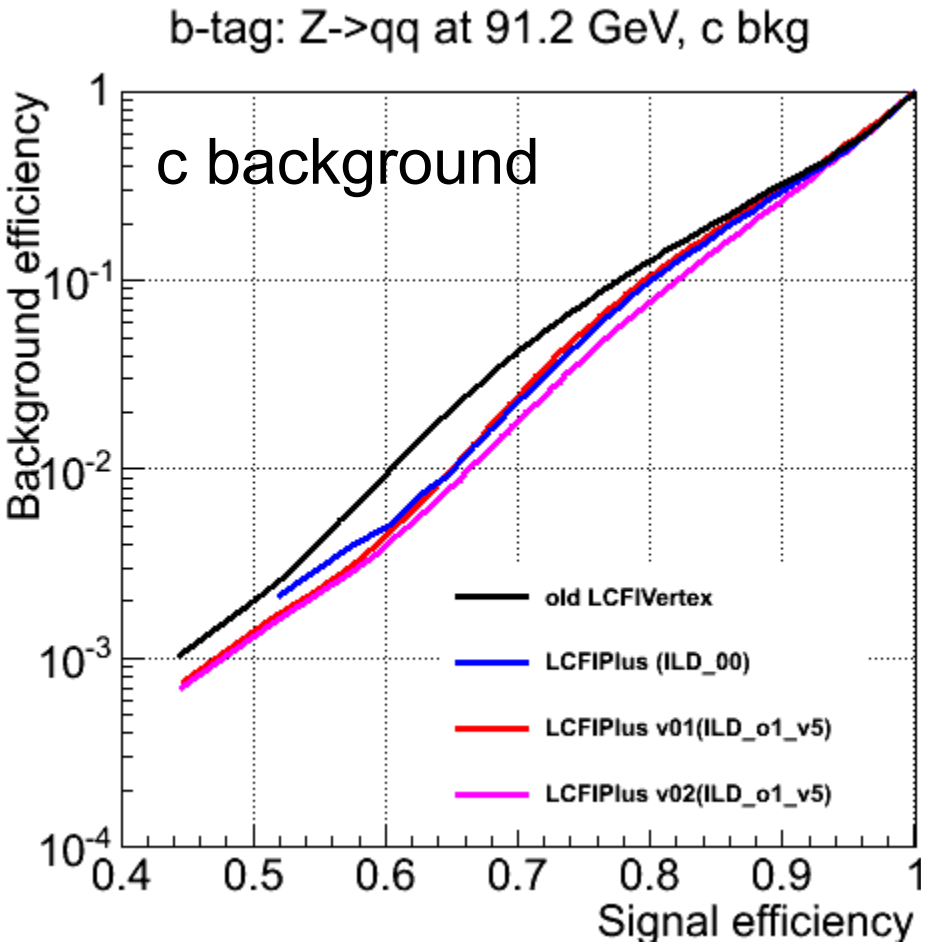
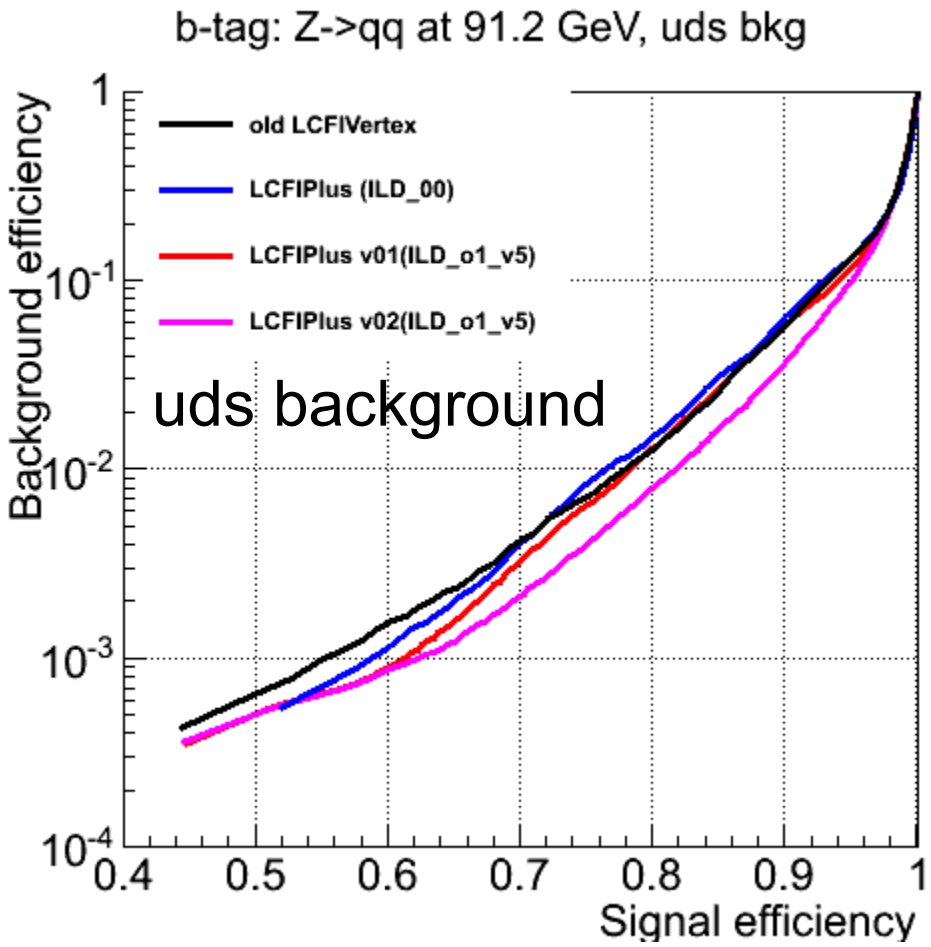


Figure 4.1.1: (Left) Average number of hits for simulated charged particle tracks as a function of polar angle. (Right) Average total radiation length of the material in the tracking detectors as a function of polar angle.

Performance





Vertex Finder

Motivated by *vertex-first, jet-second* approach, a high purity vertex finder was developed. Compared to LCFIVertex, the LCFI+ vertex finder gives:

- fewer rate of primary tracks
- better efficiency of secondary tracks
- improved V^0 rejection

in realistic multi-jet environment

(a) $ZHH \rightarrow qqbbbb$	Track origin			
	Primary	*b* hadron	*c* hadron	Other
Number of all reconstructed tracks	67575	12912	15246	4087
Number of tracks used by ZVTOP	1162	8534	10404	999
...in *good* vertices	-	8248	10103	-
Number of tracks used by our original vertex finder	617	8717	10529	358
...in *good* vertices	-	8551	10333	-

(b) $t\bar{t} \rightarrow bbqqqq$	Track origin			
	Primary	*b* hadron	*c* hadron	Other
Number of all reconstructed tracks	74504	8945	12602	4219
Number of tracks used by ZVTOP	920	5999	8353	1024
...in *good* vertices	-	5830	8137	-
Number of tracks used by our original vertex finder	420	6161	8447	341
...in *good* vertices	-	6060	8279	-

Good performance is obtained in reasonable computing time without the help of jet finders.